Numerical Simulations of Sediment Transport and Scour around Mines

Dr. Diane L. Foster
Department of Civil and Environmental Engineering and Geodetic Science
470 Hitchcock Hall, 2070 Neil Avenue
Ohio State University
Columbus, OH 43210-1275
phone: (614) 292-6420 fax: (614) 292-3780 email: foster.316@osu.edu

Award Number: N00014-01-1-0570

LONG-TERM GOALS

The long term goal of this research is to understand and predict the scour and transport of submerged objects in coastal waters.

OBJECTIVES

The objective of this research is to verify a computational fluid dynamics (CFD) model for sediment transport and scour of mines in coastal waters with laboratory and field observations. The three-dimensional flow around and scour of partially and unburied mines in the coastal zone is being simulated with a numerical CFD model for both wave and current dominated conditions. The predicted flow, sediment transport and bed scour model is being verified with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana-Champagne (UIUC); PI Richardson, Naval Research Lab; and PI Howd, University of South Florida).

APPROACH

In this research, we are modelling the three-dimensional flow field and sediment transport around submerged objects which have dimensions and characteristics similar to military mines. The FLOW-3D CFD software package is being used to solve for the flow, sediment transport, and evolution of the seabed around the mine under wave and current conditions specified at the boundaries of the numerical domain. FLOW-3D solves the nonlinear Navier-Stokes equations in three-dimensions, and uses the Volume-of-Fluid (VOF) method to track fluid-fluid or fluid-sediment interfaces (Hirt and Nichols, 1981). FLOW-3D also uses the Fractional Area/Volume Obstacle Representation (FAVOR) method to represent the complex boundaries containing the flow (Hirt and Sicilian, 1985). Using FAVOR, the boundaries of the domain (including any obstacles in the flow) can evolve in time and thus can be used to model the changes to the seafloor or to the position and orientation of obstacles, such as mines, within the flow field. FLOW-3D also allows for several turbulence closure schemes to be incorporated and tested. These closure schemes include simple eddy viscosity, one-dimensional Prandtl mixing length, two-equation *k-e*, large-eddy, and four-equation Re-Normalized Group (RNG) models.

The present module in FLOW-3D allows for the movement of sediment as a result of the shear stress exceeding the critical value required for incipient motion (developed to model the erosion of foam duct work in heat transfer problems). The deposition of sediment relies on the two-component drift flux

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE **Numerical Simulations of Sediment Transport and Scour around Mines**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Civil and Environmental Engineering and Geodetic Science,,470 Hitchcock Hall, 2070 Neil Avenue,Ohio State University,,Columbus,,OH,43210**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

module in FLOW-3D (developed to model snowdrifts in air-snow interaction problems). We are evaluating this sediment transport module with continental shelf wave and mean current flows.

The model has been evaluated with laboratory observations of flow and scour around a cylinder. It is currently being evaluated with with realistic mine geometries and non-uniform seabed topography with both laboratory (PI Fernando, ASU) and field (PI Traykovski, WHOI and PI Howd, USF) observations. The model results are being used to identify the tendency of a mine to scour or be buried, and provide guidance on the general behavioral characteristics of mines under various flow conditions.

WORK COMPLETED

We have performed investigations in both two- and three-dimensions. The two-dimensional investigations have allowed for model evaluations of both the flow (Smith and Foster, 2005) and sediment tranpsort (Smith and Foster, 2002) modules. Three-dimensional simulations on the scour and deposition around mines in both wave and mean currents have been evaluated with field observations from the Martha's Vineyard Coastal Observatory (Hatton, Foster, and Smith, 2005). On going three-dimensional investigations have also allowed for an examinations of the three-dimensional vortex shedding resulting from mean and wave current forcing.

RESULTS

The model has been used to simulate the near bed scour and deposition patterns around the mine. In accordance with the Martha’s Vineyard Coastal Observatory site, two grain sizes (fine 0.15 mm and coarse 0.75 mm sand) are considered these simulations. The effect of the mean flow orientation is explored through the use of three flow orientation: a transverse (0°), a longitudinal (90°) and an oblique (45°) orientation. Two flow speeds (20 and 0 cm/s) are also considered.

The scour around the mine is characterized with the shear velocity, u_*. This shear velocity is calculated with the model predicted near bed velocities. The shear velocity is a measure of the applied bed stress. Deposition is considered with the Rouse parameter. The Rouse parameter is a measure of the balance of the applied stress to the gravitational forces on the particle and is defined with

$$Ro = \frac{w_s}{\kappa u_*}$$

where κ is the von Karman constant (=0.41). Settling dominates for Rouse parameters larger than 10. Sediment begins to suspend at Rouse parameters less than 5, and remains in suspension for Rouse parameters less than 3.125. Figure 1 presents the shear velocity and Rouse parameter variation around the mine for the transverse flow orientation at 40 cm/s. At this velocity, the bed in completely in motion for the fine grain sand. Areas of motion for the coarse grain sand are contained in the green contour. Initiation of motion for the transverse and longitudinal (not shown) cases occurs at the upstream corners of the mine. This is consistent with field observations of large scour holes forming at the ends of the mine. Deposition occurs directly upstream and downstream of the mine along the mid-section. This is also consistent with the deposition seen in the mid-section of the mine as observed in the field.

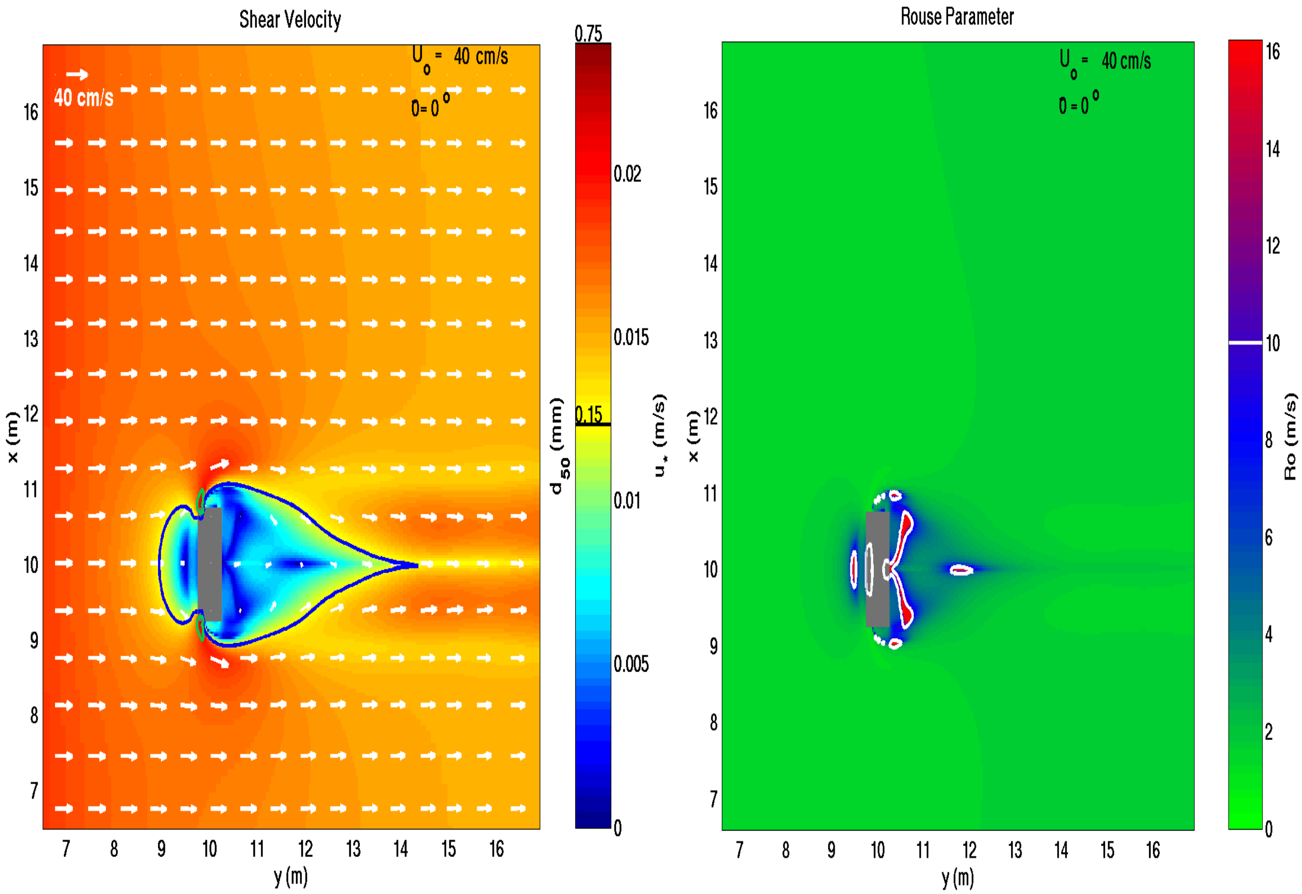

Figure 1:The shear velocity (left panel) and the Rouse parameter (right panel) for a transverse flow of 40 cm/s. The critical shear velocity for motion for both grain sizes is marked on the colorbar. The blue contour in the shear velocity plot represents areas where the fine grain sand is not in motion. The green contour presents areas where the course grain sand is in motion. The white contour in the Rouse parameter plot presents the areas where the fine grain sand will be dominated by settling. Settling dominates the entire area for the coarse grain sand.

Figure 2 presents the case for the oblique flow orientation at 40 cm/s. Again, the fine grain sand is completely in motion. Scour is initiated at the separating corners of the flow fir this case. Bed stress amplification due to the presence of the obstacle has a higher value and a larger region of influence for this case (extent of green contour). This is also seen through the very small areas of deposition for the fine grain sand in the Rouse parameter plot. The tail structure of the wake is consistent with wake of the wreck observed by UNH surveys.

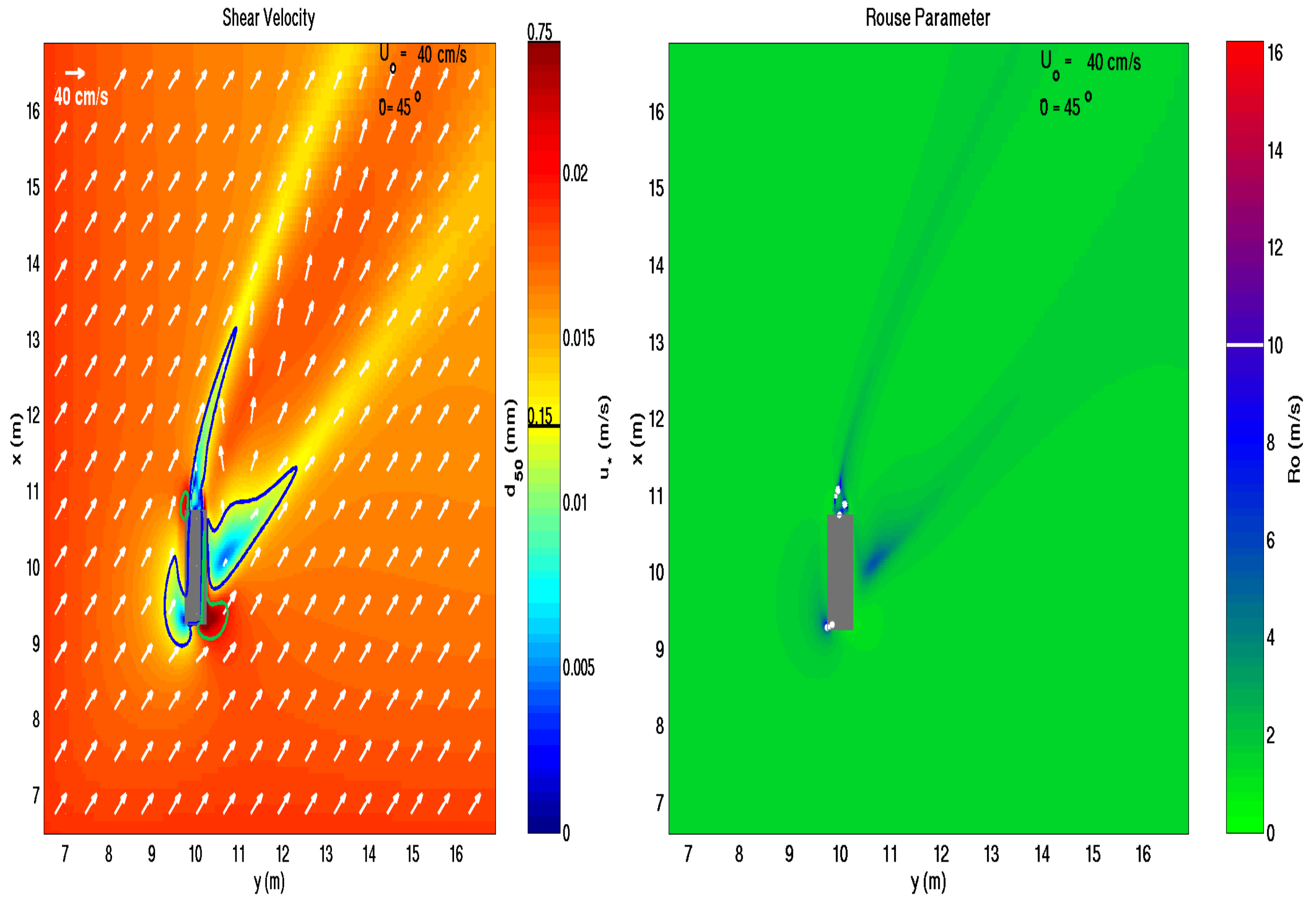

Figure 2:The shear velocity (left panel) and the Rouse parameter (right panel) for a oblique flow of 40 cm/s. The critical shear velocity for motion for both grain sizes is marked on the colorbar. The blue contour in the shear velocity plot represents areas where the fine grain sand is not in motion. The green contour presents areas where the course grain sand is in motion. The white contour in the Rouse parameter plot presents the areas where the fine grain sand will be dominated by settling. Settling dominates the entire area for the coarse grain sand.

The highly three-dimensional nature of the flow around the mine is illustrated with pathlines in Figure 3. Model prediction of these three-dimensional vortex and flow patterns is being evaluated with laboratory data obtained by Testik*, et al*. (2004). These results leave us encouraged that future investigations will continue to provide insight into the dominant physics involved in the object scour process.

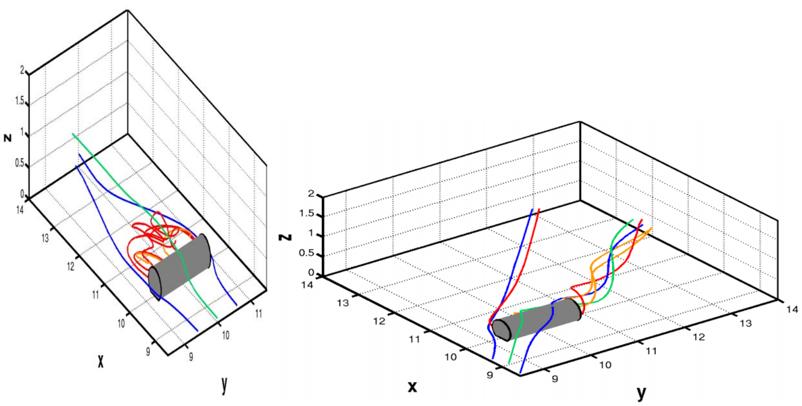

Figure 2:Pathlines for the transverse (left panel) and the oblique (right panel) cases for a flow velocity of 40 cm/s. Different paths are illustrated with different colors.

IMPACT/APPLICATIONS

This work is relevant to society and ONR's objectives in two ways. First, current models for predicting the scour of submerged objects rely heavily on empirical models based on existing laboratory observations in idealized conditions and not in natural environments. This investigation will further our understanding of the dominant physics at the fluid-sediment interface. Secondly, these results should improve our ability to predict the scour of mines, bridge piers, and other submerged objects present on the sea floor in the coastal environments

TRANSITIONS

N/A

RELATED PROJECTS

The model developed here is being compared with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana-Champagne (UIUC); PI Richardson, Naval Research Lab; PI Griffin, OMNI Technologies; and PI Howd, University of South Florida). This project will also benefit from current and future scientific exchanges with the Danish Technical University (PI's Fredsoe and Sumer).

REFERENCES

Hirt, C. W. and B. D. Nichols (1981) "Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries." *J. Comp. Physics*, 39.

Hirt C. W. and Sicilian, 1985, "A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes." *Proc. 4th Intern. Conf. Ship Hydro.* Washington, DC.

Jensen, B. L., B. M. Sumer, H. R. Jensen, J. Fredsoe (1990). "Flow around and forces on a pipeline near a scoured bed in a steady current." *Journal of Offshore Mechanics and Artic Engineering.* Vol. 112.

Testik, F.Y., Voropayev, S.I., and Fernando, R.J.S. (2004). “Three-dimensional flow under structure around short horizontal bottom cylinder under steady and oscillatory flows.” *Phys. Fluids. Submit.*

PUBLICATIONS

Hatton, K.A., Foster, D.L. and Smith, H.D. (2004). “Model-Data Comparisons of Scour and Deposition around a Cylindrical Mine.” *IEEE J. Ocean Eng*. *In prep*.

Smith, H.D. and Foster, D.L. (2005). "Modeling of Flow Around a Cylinder Over a Scoured Bed." *Journal of Waterway, Port, Coastal and Ocean Engineering. In press.*

Smith, H.D. and Foster, D.L. (2002). "Modelling of Flow and Scour Around a Pipeline." I*n Proceeding of the 28th International Conference of Coasta*l *Engineering*. Cardiff, Wales.